Parametric polarized foreground removal

Jo Dunkley
Oxford Astrophysics

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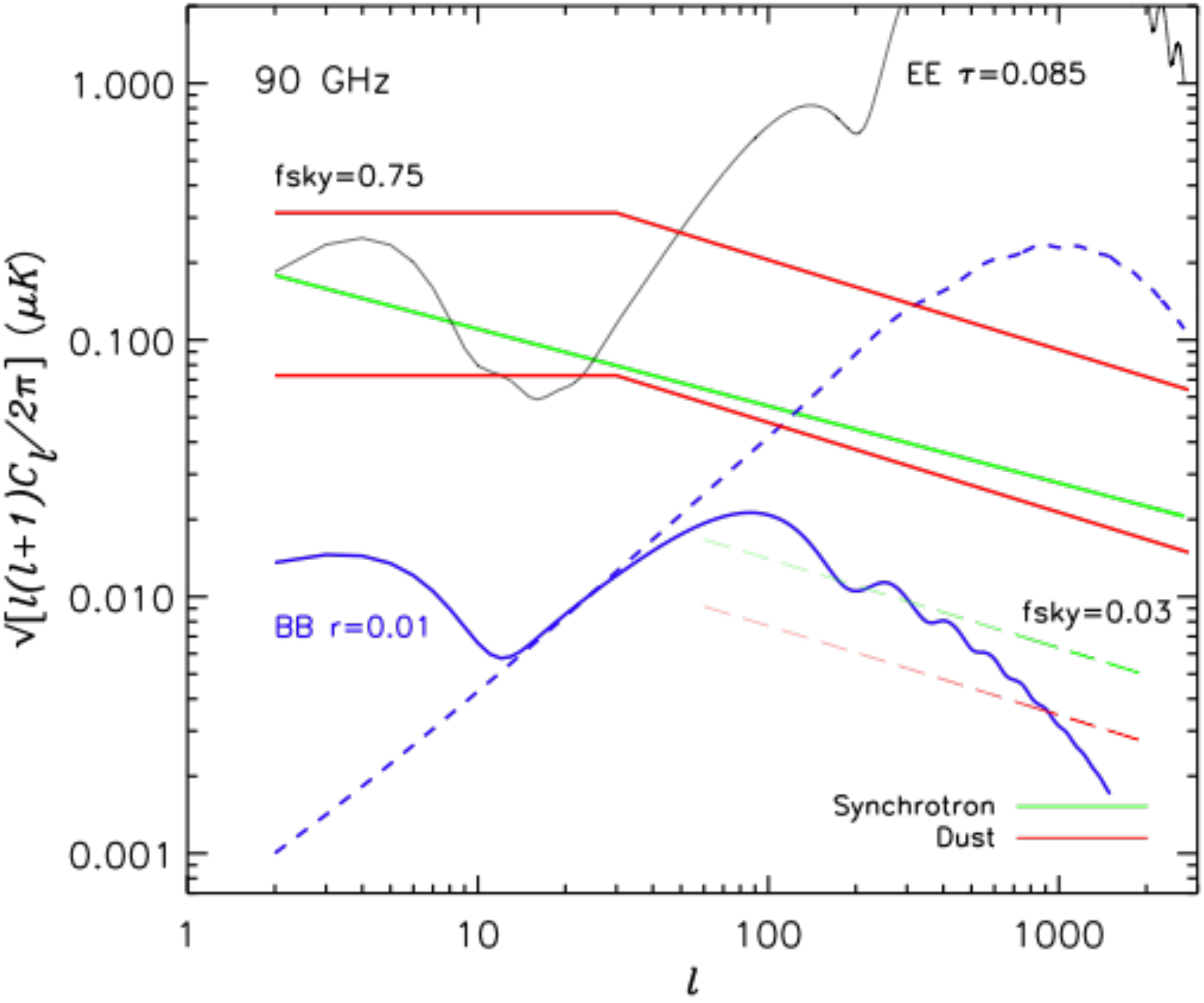
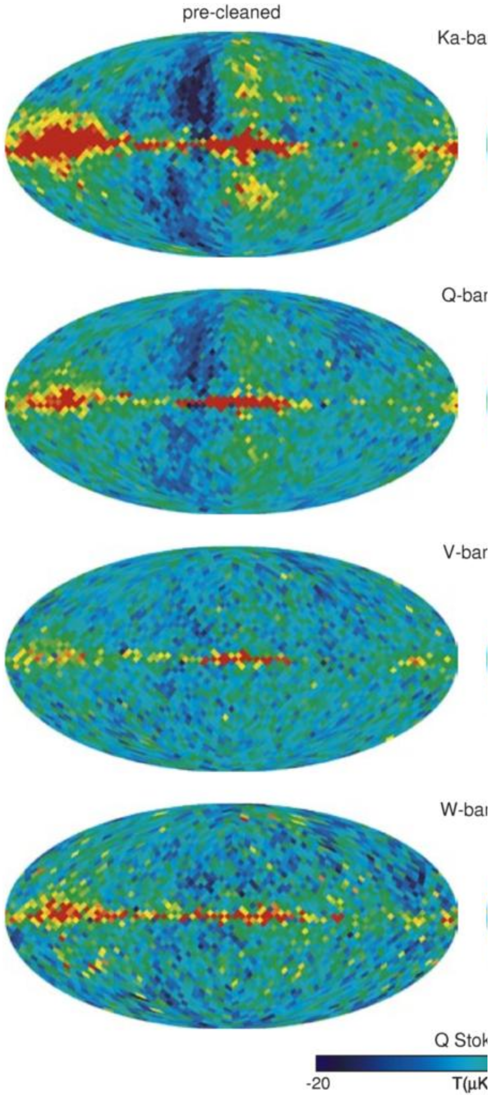


Dunkley et al 2009

The method



1 $$\mathcal{L} = \sum_{\nu} [\mathrm{d}_\nu - \mathrm{m}_\nu]^T \mathrm{N}_\nu^{-1} [\mathrm{d}_\nu - \mathrm{m}_\nu],$$

2 $$\mathbf{m}_\nu = \sum_k \boldsymbol{\alpha}_{k,\nu} \mathbf{A}_k,$$

$$\boldsymbol{\alpha}_{1,\nu} = f(\nu)\mathrm{I},$$
$$\boldsymbol{\alpha}_{2,\nu} = \mathrm{diag}[(\nu/\nu_K)^{\boldsymbol{\beta}_2}],$$
$$\boldsymbol{\alpha}_{3,\nu} = \mathrm{diag}[(\nu/\nu_W)^{\boldsymbol{\beta}_3}].$$

k=1 (CMB), k=2 (synch), k=3 (dust).
There are variations on this, which can include monopoles, multi-temp dust, spectral curvature, simultaneous spectrum estimation. Many applications to temperature maps.

Estimating parameters

Map out the joint distribution for A (amplitudes) and beta (spectral indices) vectors, and extract marginalized distribution for CMB Q/U in each pixel.

$$p(A_1, A_2, A_3, \beta_2, \beta_3 | d)$$

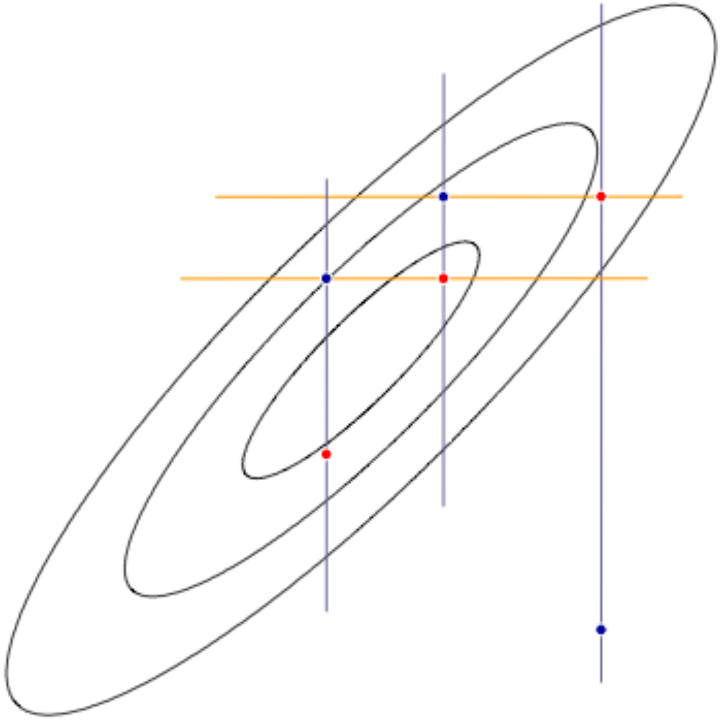
$$p(A_1 | d) = \int p(A_1, A_2, A_3, \beta_2, \beta_3 | d) dA_2 dA_3 d\beta_2 d\beta_3$$

- If maps have 7 degree pixels, this would give 2x3x768 A parameters.
- Synchrotron spectral indices - if they vary in e.g. 30 degree pixels, this gives 48 parameters, but can be thousands.
- p(A,b|d) is not a distribution we can draw analytic samples from

Gibbs sampling

Minimal case:

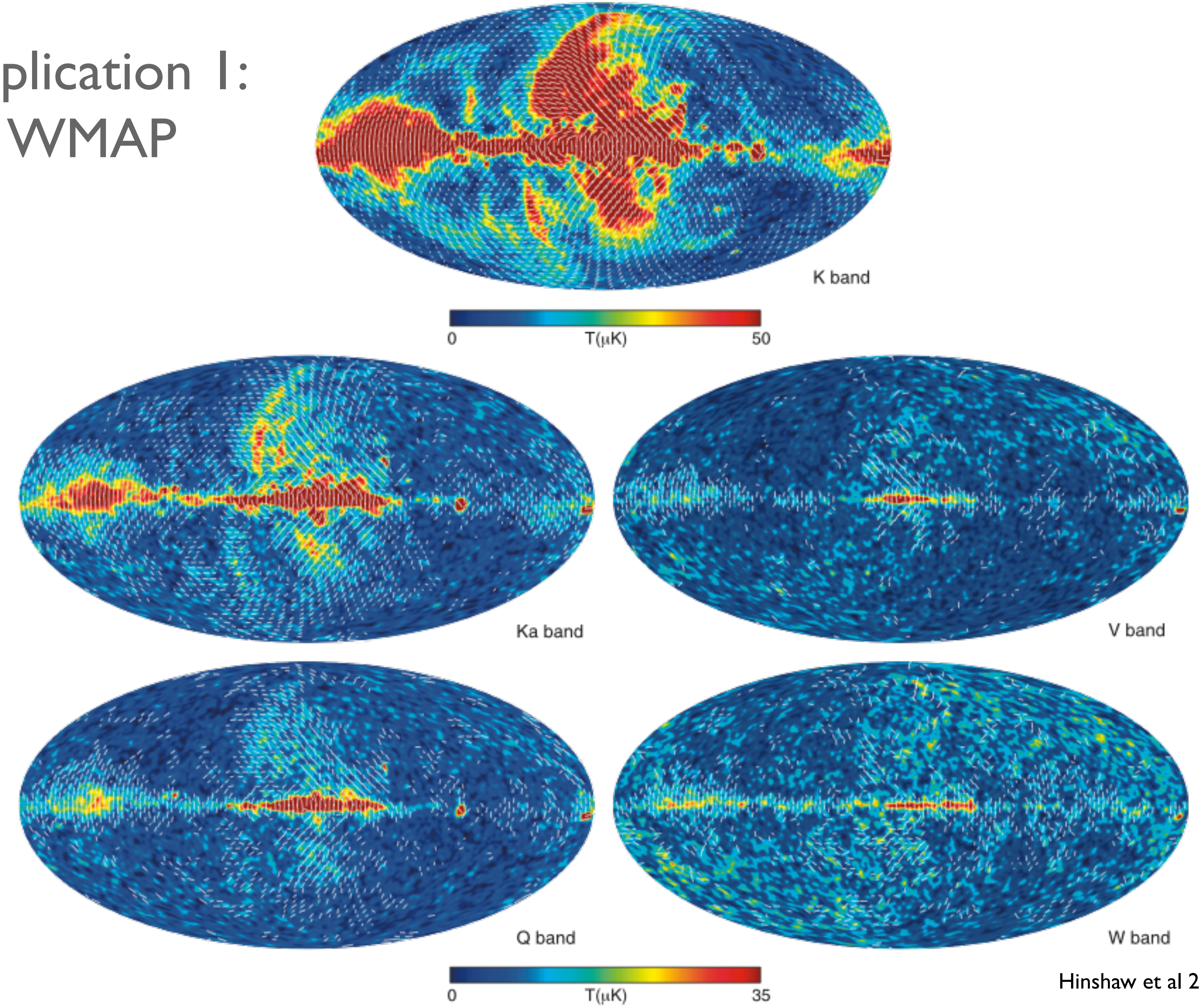
1. For fixed beta, p(A|b,d) is Gaussian, so we draw a new A sample.
2. For fixed A, p(b|A,d) is not known so draw a new beta sample using Metropolis algorithm, or other sampling method.
3. Draw A and beta samples in turn until mapped out full distribution



$$\mathcal{L} = \sum_{\nu}[\mathsf{d}_{\nu} - \sum_{k} \alpha_{k,\nu}\mathsf{A}_{k}]^{T}\mathsf{N}_{\nu}^{-1}[\mathsf{d}_{\nu} - \sum_{k} \alpha_{k,\nu}\mathsf{A}_{k}]$$

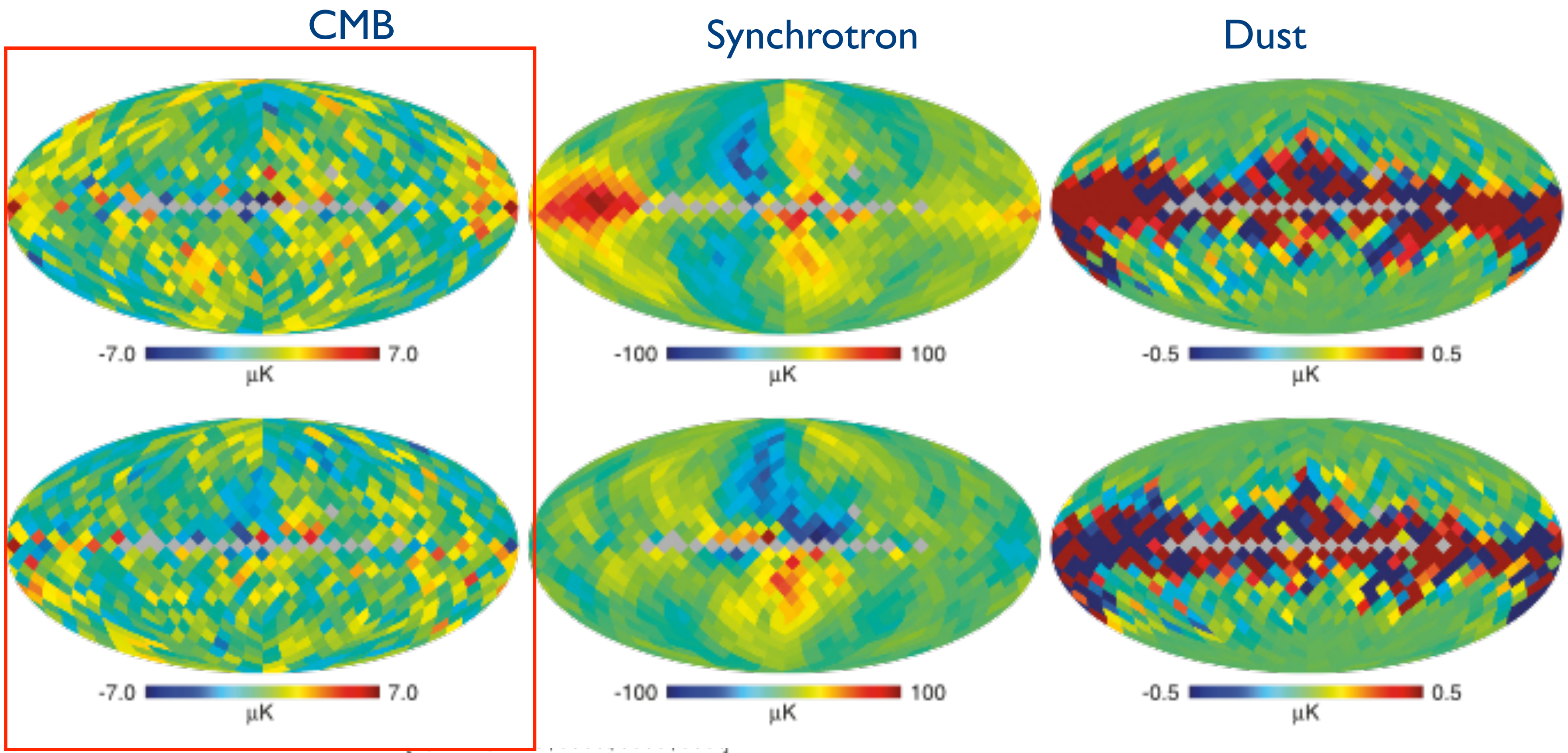
Application to data and to sims

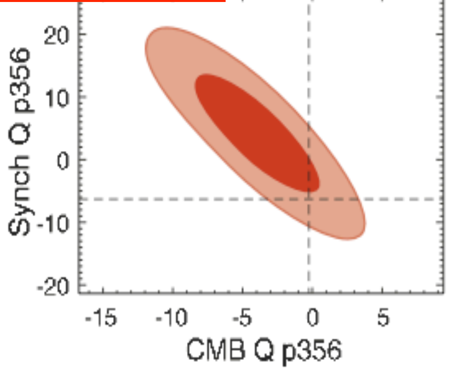
Application 1: WMAP



Hinshaw et al 2008

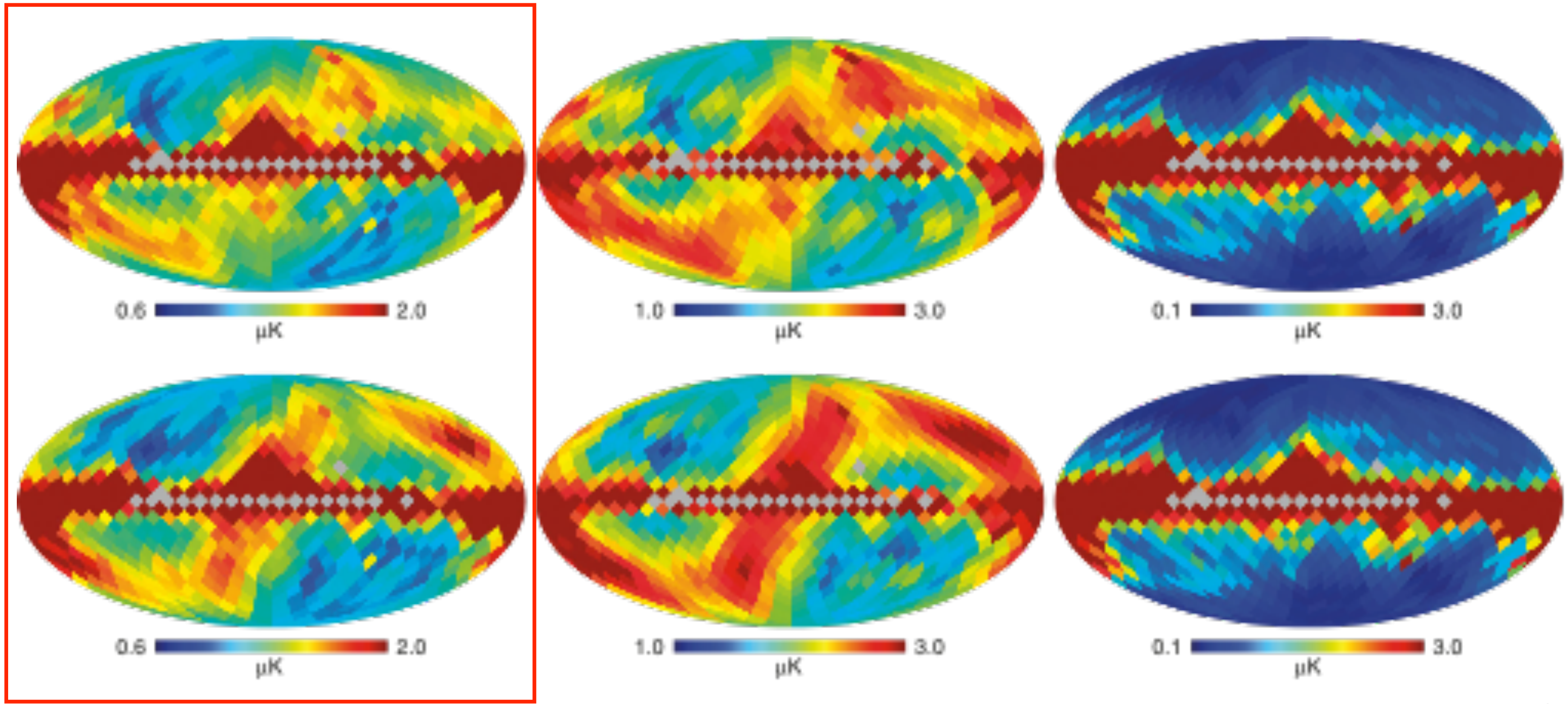
Estimated maps





Dunkley et al 2009

Estimated errors



Dunkley et al 2009

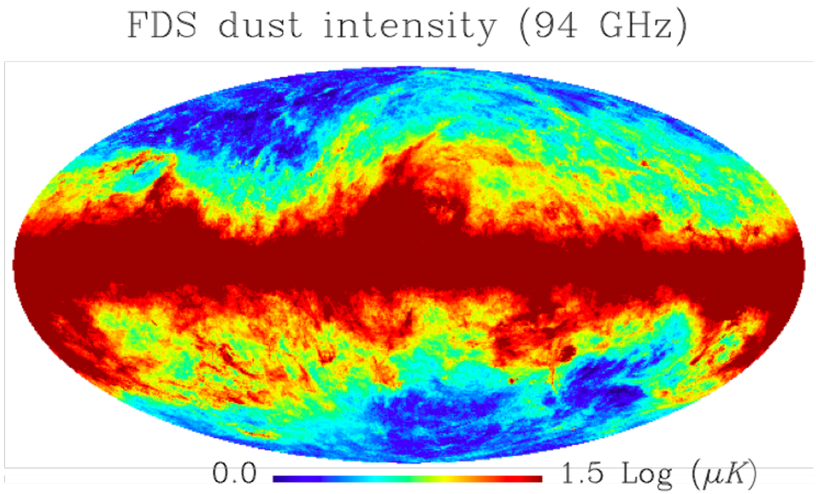
Feed maps and covariance matrix into low-ell likelihood.

Gave consistent results for large scale CMB power and tau:

$\tau = 0.091 \pm 0.019$ (parametric)

$\tau = 0.086 \pm 0.017$ (template)

But, needed priors

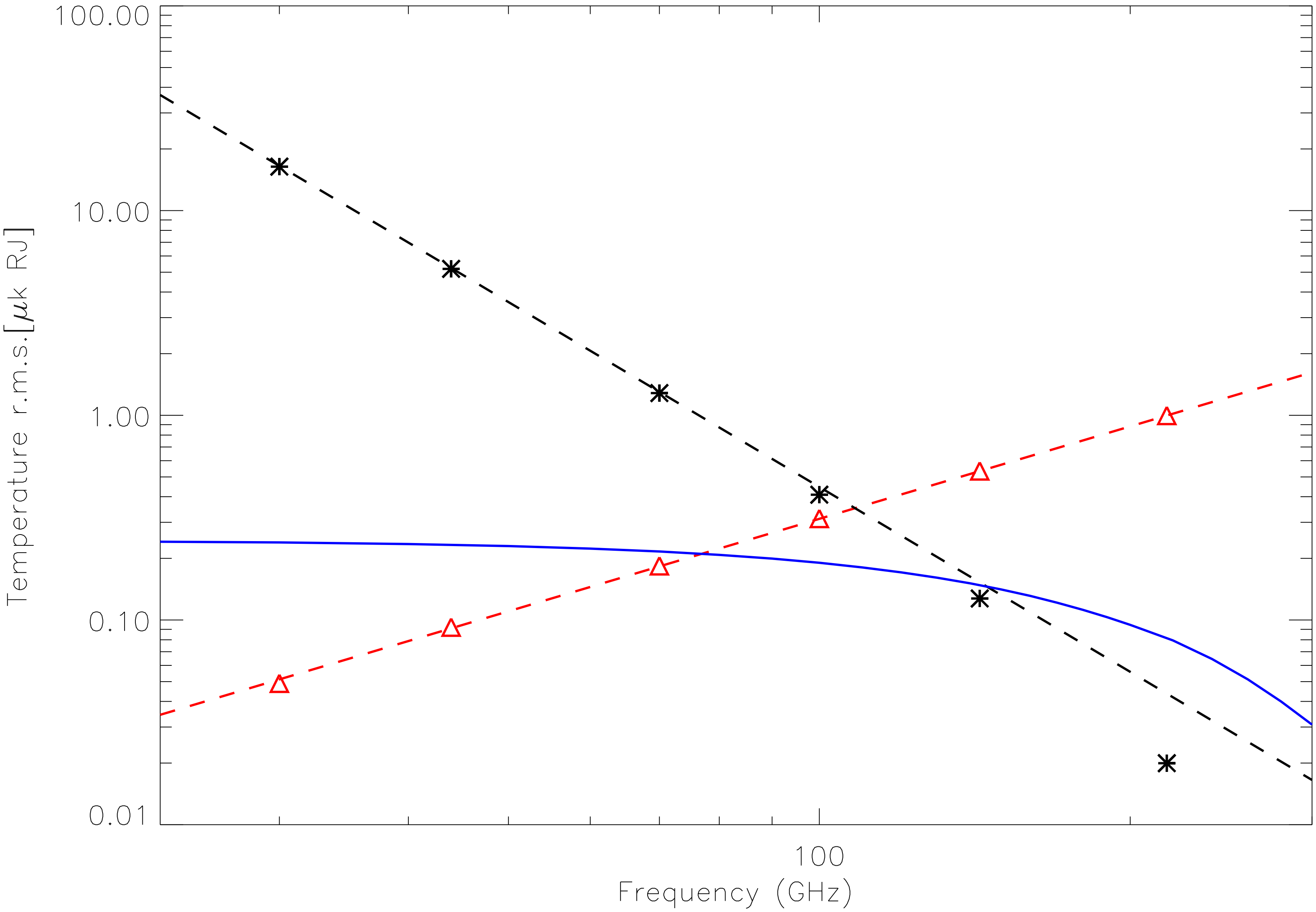


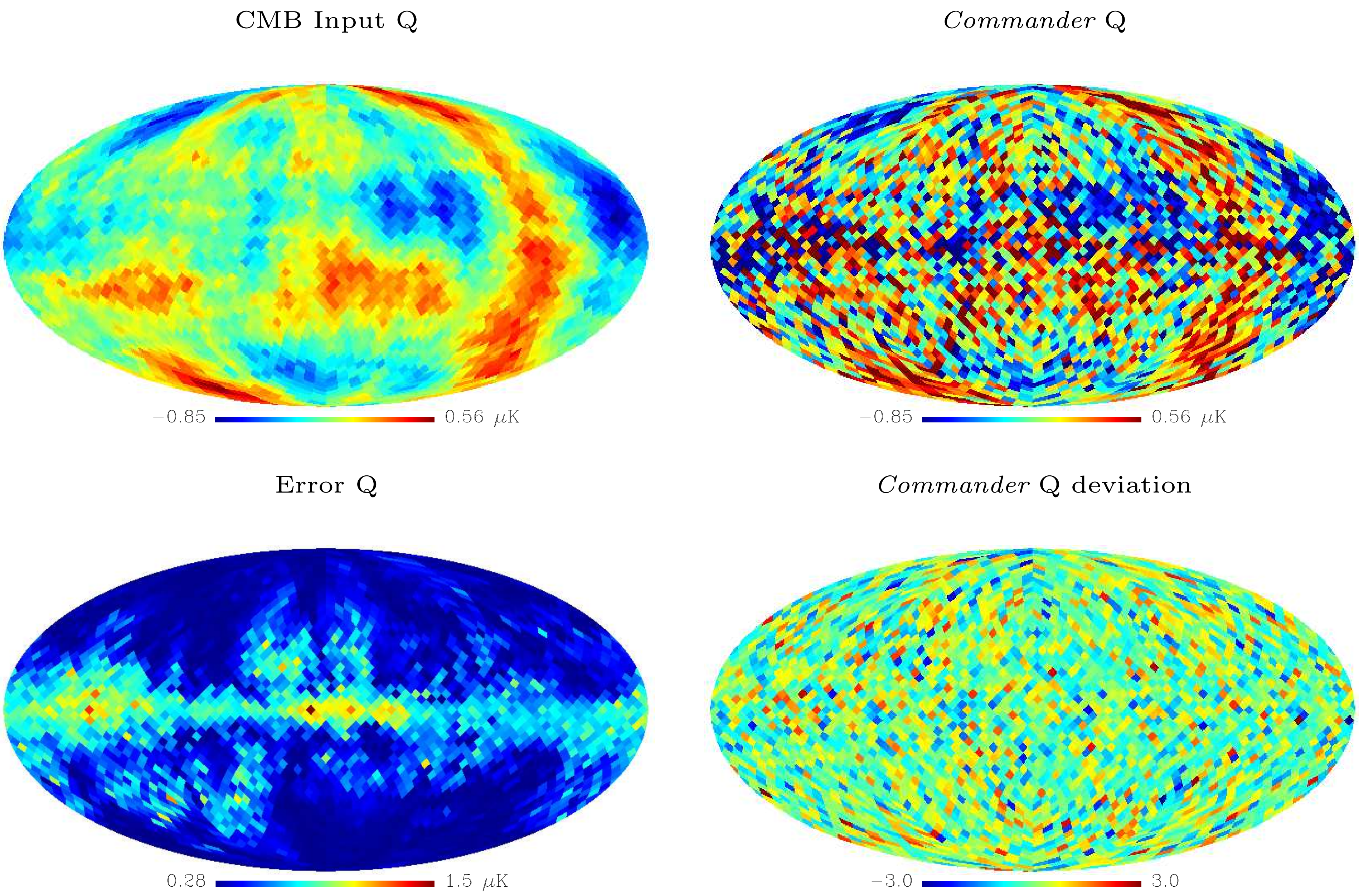
$$Q_d(n) = 0 \pm 0.2 I_d(n)$$
$$U_d(n) = 0 \pm 0.2 I_d(n)$$

$$\beta_s = -3.0 \pm 0.3 \longleftarrow$$ In pixels of side ~30 degrees

$$\beta_d = 1.7$$

Application 2: Planck-like sims





CMB Input Q

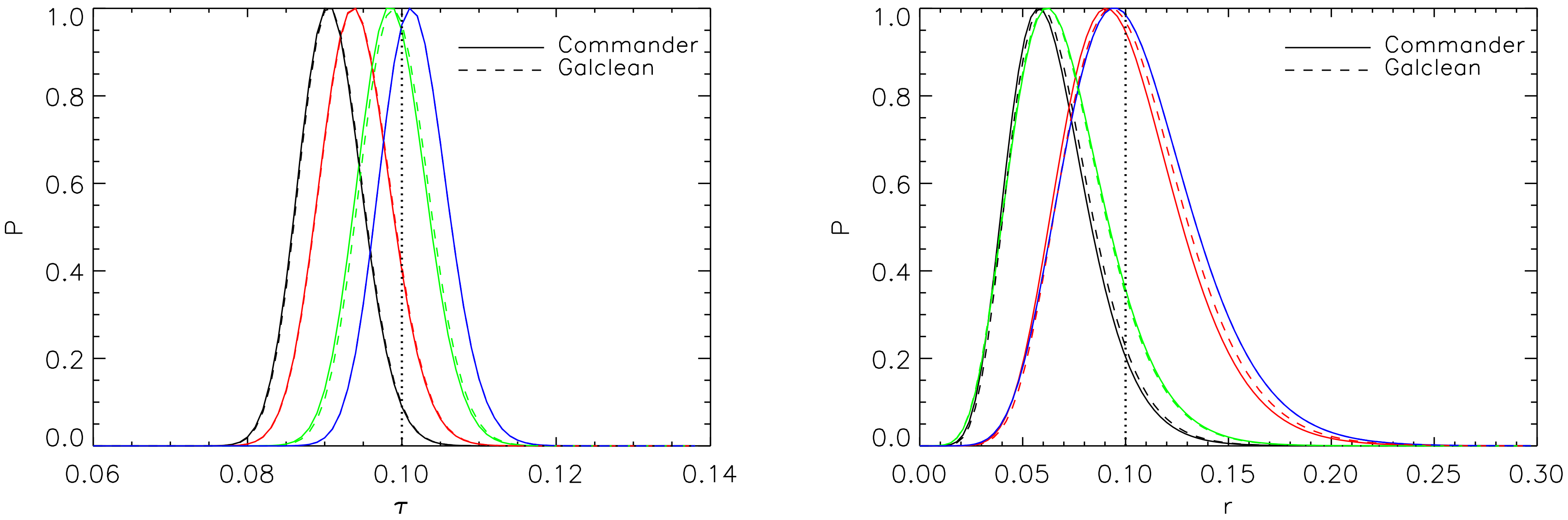
Commander Q

Error Q

Commander Q deviation

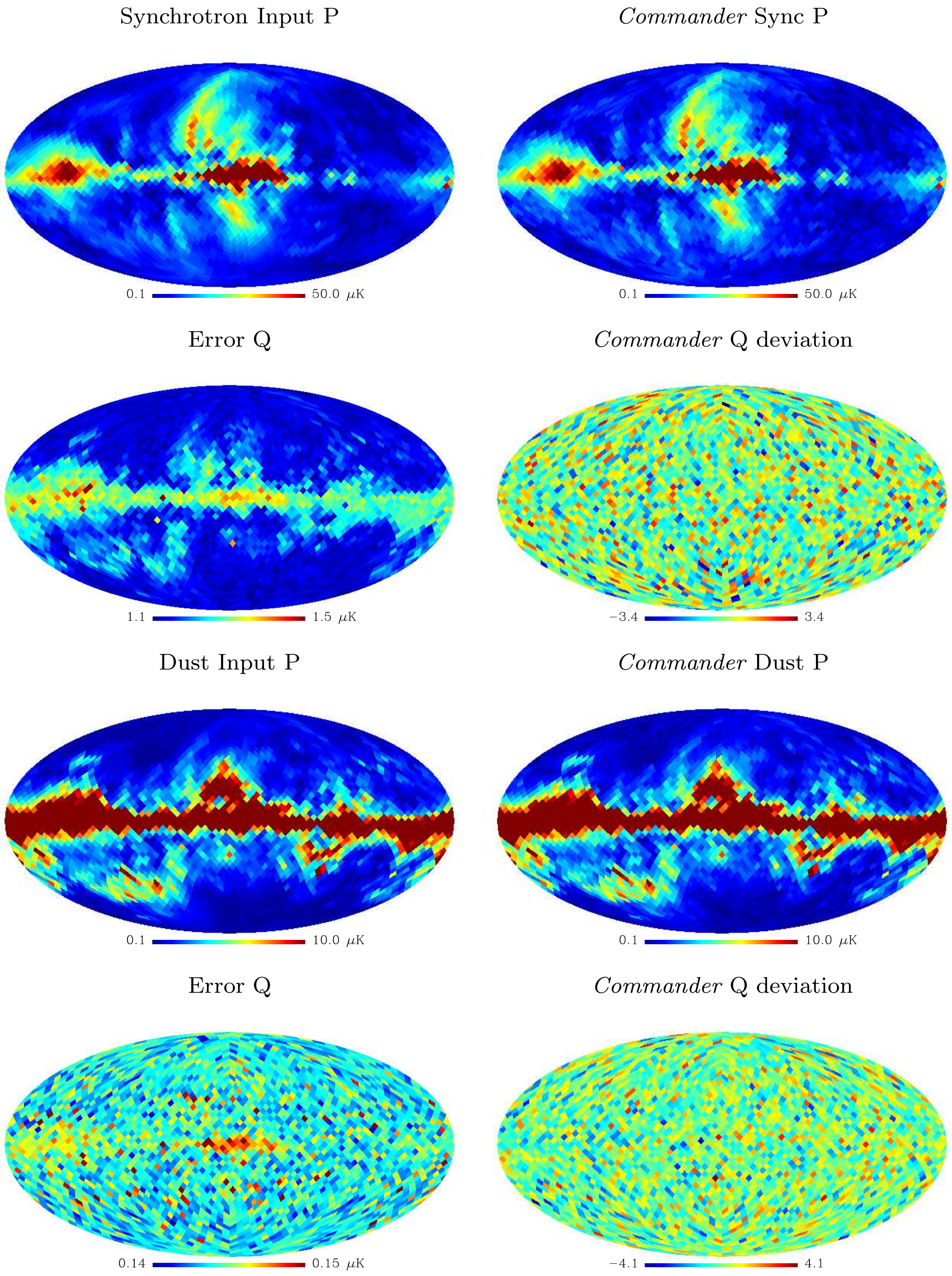
Same results, two different codes: Galclean and Commander

Armitage-Caplan et al 2011, 1103.2554



Armitage-Caplan et al 2011

Recover input optical depth and tensor-to-scalar ratio


Synchrotron Input P

Commander Sync P

Error Q

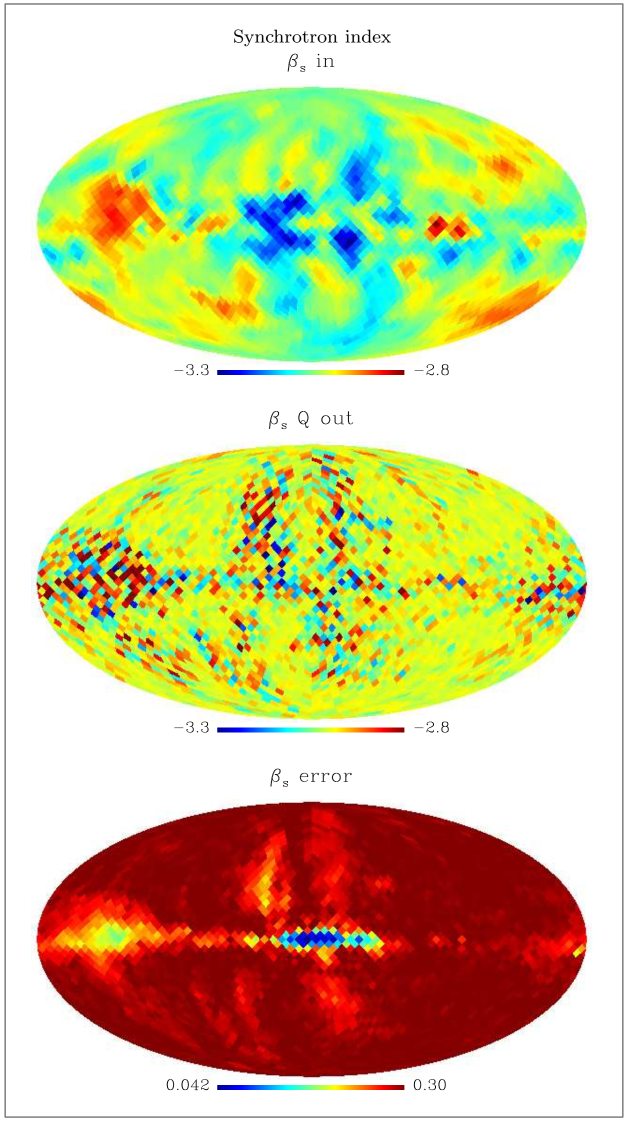
Commander Q deviation

Dust Input P

Commander Dust P

Error Q

Commander Q deviation


Synchrotron index

β_s in

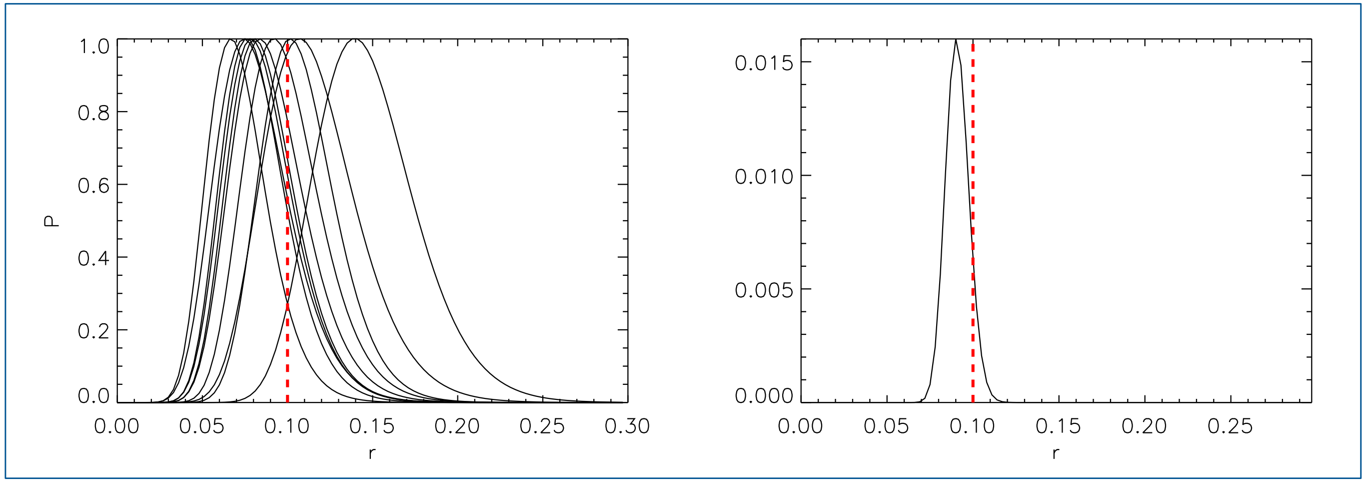
β_s Q out

β_s error

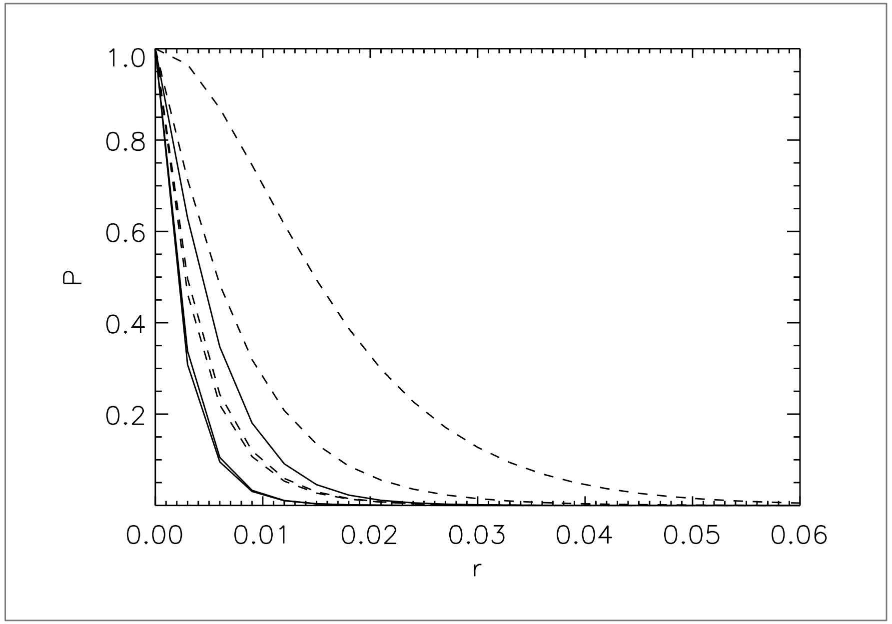
Index prior -3+-0.3

Armitage-Caplan et al 2011

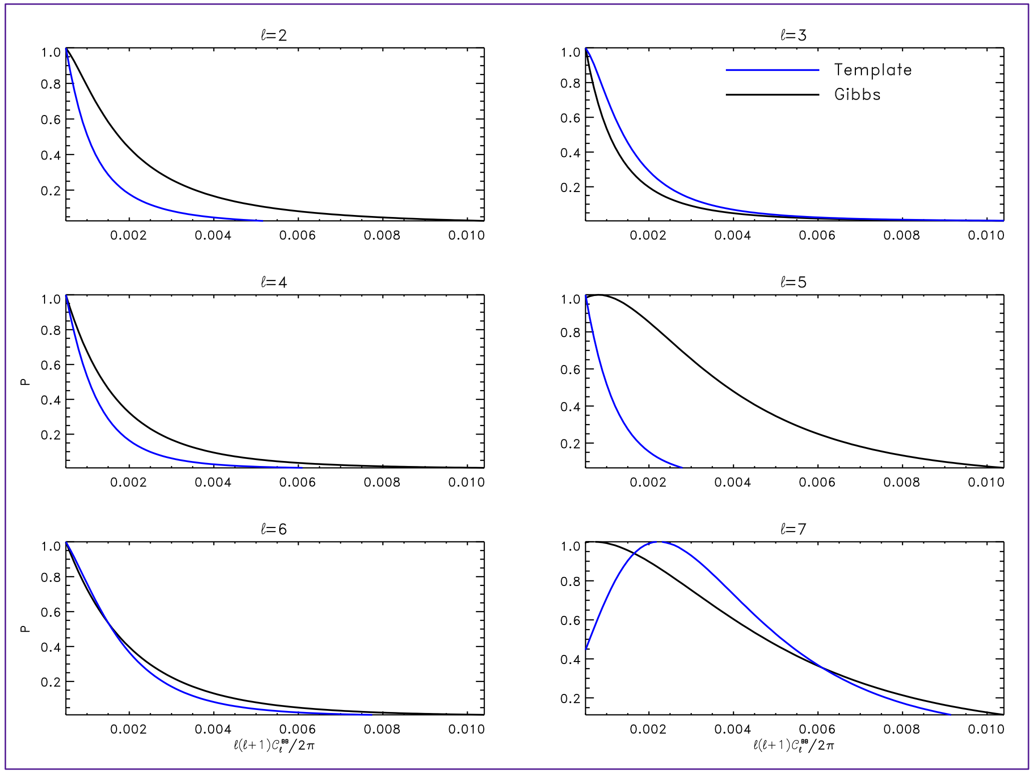
1. Test on fg-free sims



Armitage-Caplan et al 2011



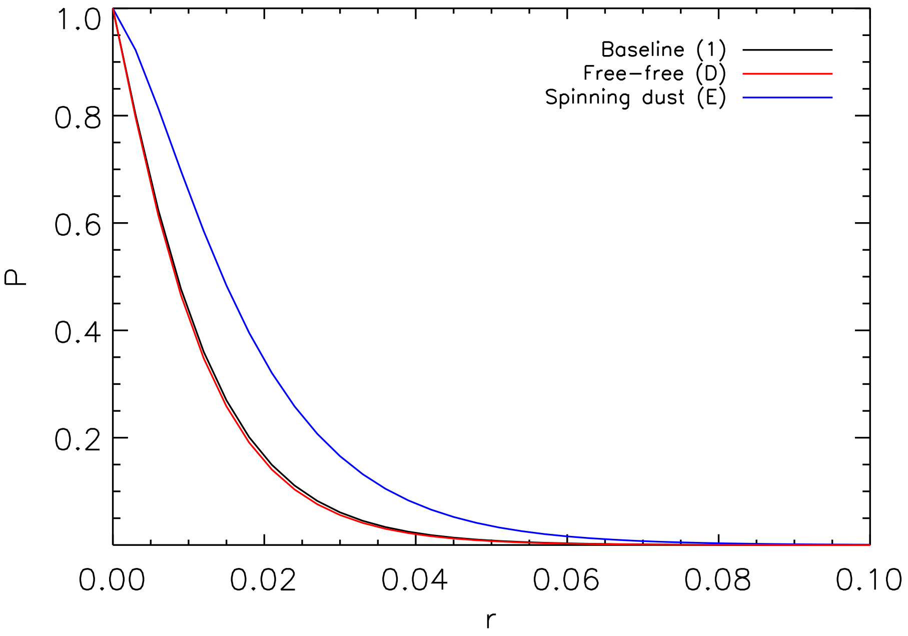
2. Error inflation with fg included

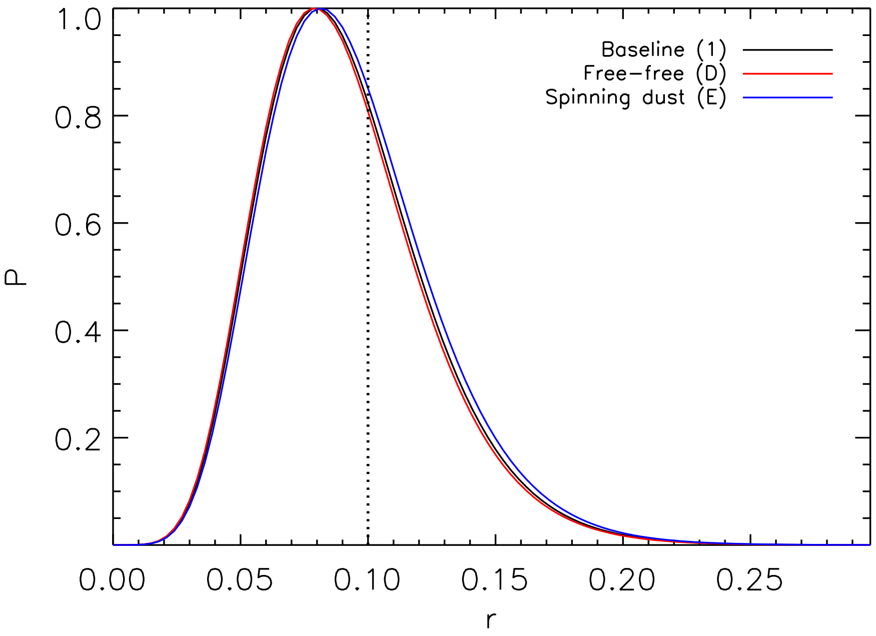


3. Compare to template-cleaning

What if we get modeling wrong?

Missing components

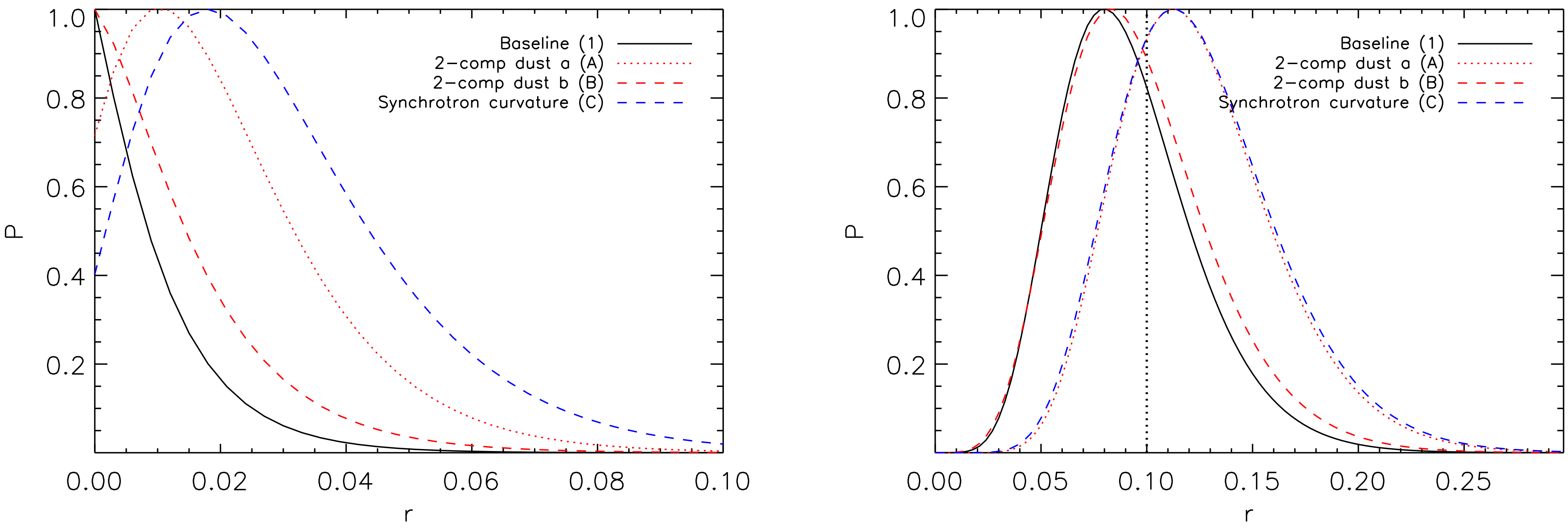




Armitage-Caplan et al 2012

- Insert 1% polarized spinning dust or free-free

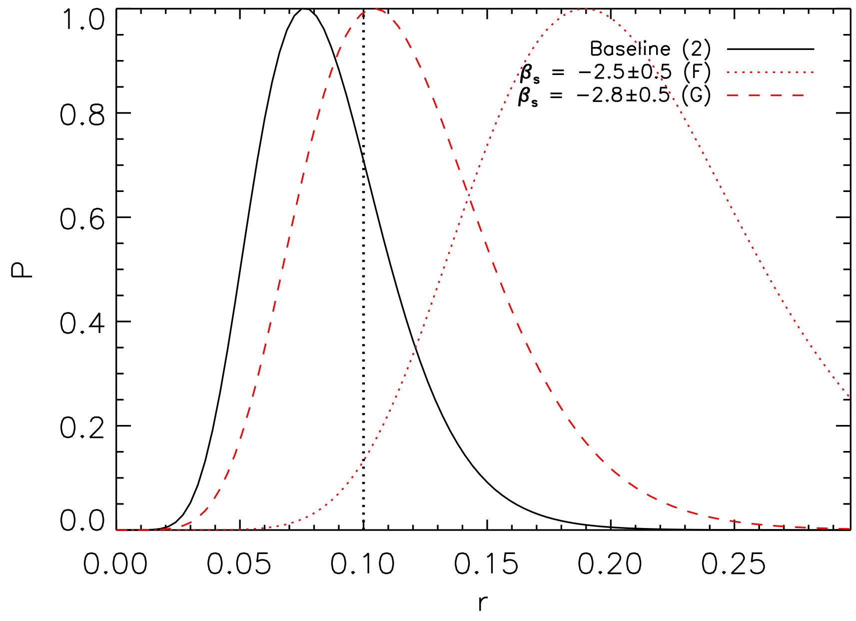
Incorrect spectral model

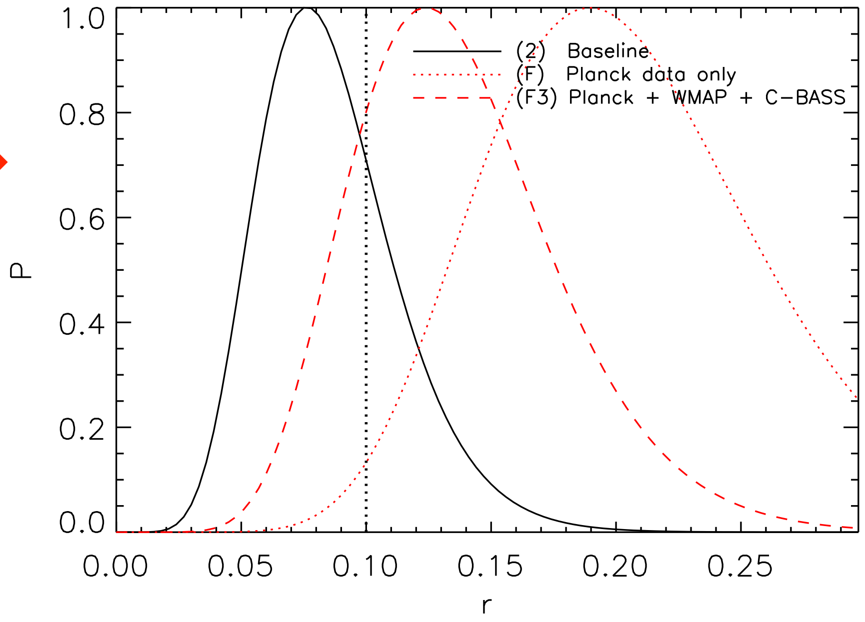


Armitage-Caplan et al 2012

- Assume power-law when modified grey-body
- Assume one-component when two-component
- Assume no curvature when really has curvature (0.3 from 30-100 GHz)

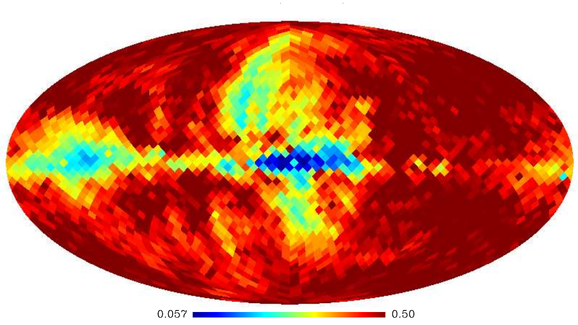
Wrong priors

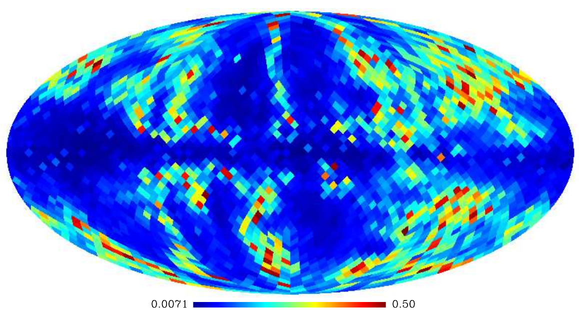




Armitage-Caplan et al 2012

- Assume synch prior -2.5±0.5 or -2.8±0.5 in 4 deg pixels, when really -3.0
- Same effect for dust
- Same effect for r=0
- Increasing S/N with C-BASS helps





0 < sigma < 0.5

Some observations

1. Method can return wrong answer where S/N is low, if applied blindly.
2. Be very careful when imposing priors, or over-parameterizing model.
3. Also be careful under-parameterizing model!
4. All modeling errors over-predict r
5. However, properly treated, this formalism is powerful: it inflates CMB error to account for foreground uncertainty.
6. So far, limited application beyond reionization bump → to go for l~100 need to think about how to include spectral variation. In fact, spatial coherence is missing in most models.

Summary

- So far, polarized foreground removal has not required more than simple template cleaning.
- But, parameterizing the foregrounds, and marginalizing over their parameters, allows for more rigorous error propagation, which is much more important for smaller CMB signals.
- The community has codes ready to do this, but the models may not be most ‘elegant’.
- It is clear that care must be taken in how the model is set up, avoiding too much freedom in low S/N regime.